PB85-181139

Review of New Source Performance Standards for Ammonium Sulfate Manufacture

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Feb 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB 85-181139

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-85-004
February 1985

Air

EPA

Review of New Source Performance Standards for Ammonium Sulfate Manufacture

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-85-004	2.
3. RECIPIENT'S ACCESSION NO. PB85 181139/AS	
4. TITLE AND SUBTITLE Review of Standards of Performance for Ammonium Sulfate Manufacture	5. REPORT DATE February 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Director for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/200/04
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

This report presents the findings of the 4-year review of the new source performance standards for ammonium sulfate manufacture. Affected facilities are those dryers at plants that manufacture ammonium sulfate as a caprolactam by-product, as a coke oven by-product, or by synthetic manufacture (direct combination of ammonia and sulfuric acid).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Pollution Control Ammonium Sulfate Manufacturing Caprolactam	Air Pollution Control Stationary Sources	13b

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 56
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-450/3-85-004

Review of New Source Performance Standards for Ammonium Sulfate Manufacture

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

February 1985

This report has been reviewed by the emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available through the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, or from National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

TABLE OF CONTENTS

		Page
	LIST OF FIGURES	v
	LIST OF TABLES	vi
1.	Executive Summary	1-1
	1.1 Regulatory History of Current Standard	1-1
	1.2 Best Demonstrated Control Technology	1-2
	1.3 Enforcement of NSPS	1-2
	1.4 Industry Growth Trends	1-3
	1.5 Economic Considerations Affecting the NSPS	1-3
2.	Industry Description	2-1
	2.1 Introduction	2-1
	2.2 Background Information	2-4
	2.3 Ammonium Sulfate Production	2-5
	2.3.1 Caprolactam By-Product Ammonium Sulfate	2-5
	2.3.2 Synthetic Ammonium Sulfate	2-9
	2.3.3 Coke Oven By-Product Ammonium Sulfate	2-12
	2.4 References	2-17
3.	Current Standards for Ammonium Sulfate Plants	3-1
	3.1 Affected Facilities	3-1
	3.2 Controlled Pollutants and Emission Levels	3-1
	3.3 Monitoring Requirements	3-1
	3.4 Testing Requirements	3-2
4.	Status of Control Technology	4-1
	4.1 Emission Sources	4-1
	4.2 Emission Control Equipment in Ammonium Sulfate Industry	4-3
	4.2.1 Venturi Scrubbers	4-6
	4.2.2 Centrifugal Scrubbers	4-6
	4.2.3 Other Wet Scrubbers in the AS Industry	4-7
	4.2.4 Fabric Filtration in the AS Industry	4-7
	4.3 Plant Testing	4-8
	4.4 References	4-10
5.	Compliance Test Results	5-1
	5.1 References	5-3

TABLE OF CONTENTS

		Page
6.	Cost Analysis	6-1
6.1	Capital Costs	6-1
6.2	Annualized Costs	6-5
6.3	Cost Effectiveness	6-10
6.4	References	6-13

LIST OF FIGURES

Figure No.		Page
2-1	Caprolactam By-Product Ammonium Sulfate Process Flow Diagram	2-6
2-2	Synthetic Ammonium Sulfate Process Flow Diagram	2-10
2-3	Process Flow Diagram for Coke Oven By-Product Ammonium Sulfate Showing Alternate Drying Processes	2-14

LIST OF TABLES

Table No.		Page
2-1	U.S. Production and Consumption of Ammonium Sulfate	2-2
2-2	Typical Parameters for a Caprolactam By-Product Ammonium Sulfate Dryer	2-8
2-3	Typical Parameters for a Synthetic Ammonium Sulfate Dryer	2-11
2-4	Estimated Parameters for a Coke Oven By-Product Ammonium Sulfate Dryer	2-16
4-1	Summary of Uncontrolled Emission Data from EPA Emission Tests on AS Dryers	4-2
4-2	Ammonium Sulfate Industry-Supplied Wet Scrubber Performance Data	4-4, 4-5
4-3	AS Particulate Control Systems Tested by EPA	4-9
4-4	Results of EPA Emission Testing	4-10
5-1	Industry-Supplied Emission Test Data	5-2
6-1	Capital Cost Summary for a Venturi Scrubbing System (Caprolactam By-Product Plant with 22.7 Mg/hr Capacity)	6-2
6-2	Capital Cost Summary for a Venturi Scrubbing System (Synthetic Plant with 13.6 Mg/hr Capacity)	6-3
6-3	Capital Cost Summary for a Venturi Scrubbing System (Coke Oven By-Product Plant with 2.7 Mg/hr Capacity)	6-4
6-4	Venturi Scrubber Operating Parameters	6-6
6-5	Annualized Cost Summary for a Venturi Scrubbing System (Caprolactam By-Product Plant with 22.7 Mg/hr Capacity)	6-7

LIST OF TABLES

Table No.		Page
6-6	Annualized Cost Summary for a Venturi Scrubbing System (Synthetic Plant with 13.6 Mg/hr Capacity)	6-8
6-7	Annualized Cost Summary for a Venturi Scrubbing System (Coke Oven By-Product Plant with 2.7 Mg/hr Capacity)	6-9
6-8	Average U.S. Retail Price for Ammonium Sulfate	6-11
6-9	Cost Effectiveness of AS Particulate Recovery Using Venturi Scrubbers (March 1984 dollars)	6-12

1. EXECUTIVE SUMMARY

1.1 Regulatory History of Current Standard

The new source performance standards (NSPS) for ammonium sulfate (AS) particulate matter were proposed on February 4, 1980, and promulgated by the Environmental Protection Agency (EPA) on November 12, 1980 (40 CFR 60, Chapter 1, Subpart PP). The standards apply to ammonium sulfate dryers that were constructed, reconstructed, or modified on or after February 4, 1980, and produce ammonium sulfate as a caprolactam by-product, as a coke oven by-product, or by synthetic manufacture (direct combination of ammonia and sulfuric acid). The standards state that exhaust gases discharged to the atmosphere from ammonium sulfate dryers must not contain AS particulate matter in excess of 0.15 kg per megagram of ammonium sulfate produced (0.30 pound of particulate per ton of ammonium sulfate produced). The standards also limit visible emissions from stacks to 15 percent opacity.

There are requirements in the NSPS for continuous monitoring of mass flow rates to crystallizers and for the continuous monitoring of pressure drops across particulate control equipment. The flow monitoring device must have an accuracy of $\pm$ 5 percent. However, if a facility uses weigh scales of the same accuracy to directly measure production rates of AS, the use of flow monitoring devices is not required. The NSPS requires that affected facilities install, calibrate, maintain, and operate pressure drop monitors across emission control devices, and that these devices be accurate to $\pm$ 5 percent. Records from AS feedstream flow monitoring and pressure drop monitoring are required under the NSPS to be retained for 2 years from the date the measurements are made by the operator.

The objective of this report is to review the ammonium sulfate NSPS and to assess the need for revision on the basis of developments that have occurred since the NSPS was promulgated in 1980.

1.2 Best Demonstrated Control Technology (BDCT)

The NSPS is based on the use of medium energy venturi scrubbers as an add-on measure to control particulate emissions from AS dryers. No significant changes in control technology for AS dryers have occurred since promulgation of the NSPS. Because ammonium sulfate has a moderately high water solubility, wet scrubbing is employed throughout the industry. Wet scrubbing allows easy recycle of collected particulates back into process streams, avoiding alternative waste disposal problems. In the caprolactam by-product AS industry there are small amounts of caprolactam carried through the AS manufacturing process. Dryer emissions of caprolactam, a volatile organic compound (VOC), are also controlled effectively by wet scrubbing.

There is only one dry emission control process that has operated at an AS facility. This is a baghouse which was used at a synthetic AS plant. A telephone survey of the synthetic AS industry indicates that this plant has been mothballed since 1979.

1.3 Enforcement of NSPS

Since proposal and promulgation of the NSPS, there have been no new, modified, or reconstructed facilities which have come under the standards. However, emission data gathered from the industry since promulgation of the NSPS indicate that emission levels set by the NSPS are being achieved at existing plants. There is an incentive for AS producers to meet the NSPS because captured emissions may be recovered, reprocessed, and sold as

product. There are no in-stack opacity monitors in most AS particulate control applications due to the use of wet scrubbing . Water droplets and steam in the stack make the exhaust gases difficult to monitor by available equipment. Therefore, no continuous opacity data are available for AS dryers.

1.4 Industry Growth Trends

Since proposal and promulgation of the NSPS there has been a decline in the total production capacity of ammonium sulfate plants. Several plants producing synthetic AS and coke oven by-product AS have closed operations. Caprolactam by-product AS has experienced a small capacity increase, but the potential for further AS growth in the near future is limited by the demand for caprolactam, which is used to manufacture nylon-6 fibers. Consumption of ammonium sulfate has also experienced a decline in the last 4 years due to an increased use of alternative nitrogenous fertilizers. There are no indications that these production and consumption patterns will be altered in the next few years.

1.5 Economic Considerations Affecting the NSPS

A review of venturi scrubber costs in the AS industry was performed to determine the cost effectiveness of achieving the NSPS for each of the three regulated AS processes. The cost effectiveness of venturi scrubbers ranges from a cost savings of $36 per megagram of particulate captured for a 545 Mg/day caprolactam plant to a cost of $655 per megagram for a 65 Mg/day coke oven by-product plant. There is a cost savings of $21 per Mg for a 326 Mg/day synthetic AS plant. Cost savings are generated by recovery credits for AS particulates that are captured by scrubbers and recycled back to process streams. Recovery credits are dependent on dryer emission rates, scrubber collection efficiencies, and AS market prices.

2. INDUSTRY DESCRIPTION

2.1 Introduction

On February 4, 1980, the EPA proposed new source performance standards for ammonium sulfate dryers. The standards established particulate emission limits for ammonium sulfate dryers in three categories of ammonium sulfate production. Affected facilities include dryers in synthetic process plants, caprolactam by-product plants, and coke oven by-product plants that were constructed, reconstructed, or modified on or after February 4, 1980. The proposed standards were promulgated on November 12, 1980. Ammonium sulfate is produced as a by-product of several other processes, such as nickel reduction, sulfuric acid tail gas scrubbing, and sewage sludge processing, none of which are subject to the NSPS.

At the time of the NSPS development, there were approximately 50 plants employing one of the three regulated processes for production of ammonium sulfate. Production capacity has declined between 1977 and 1983 from 3,143 x 10^3 Mg/yr to 2,869 x 10^3 Mg/yr with several plant closings in the industry.[1] U. S. consumption of ammonium sulfate has dropped from 955 x 10^3 Mg in 1977 to 624 x 10^3 Mg in 1983.[2] Production and consumption trends are presented in Table 2-1.

There are three plants currently producing AS as a by-product of caprolactam, and these three plants produce over 50 percent of the total AS in the United States. Caprolactam is used in the manufacture of nylon-6 fibers. One caprolactam plant expanded AS production in 1980-81 from 860 x 10^3 to 910 x 10^3 Mg/yr, but the modification was exempt from the NSPS

TABLE 2-1. U.S. PRODUCTION AND CONSUMPTION OF AMMONIUM SULFATE
(10^3 Metric tons)

Year	Production Capacity	Production Rate (% Capacity)	Actual Production	Consumption
1983	2869*	N.A.	N.A.	624
1982	2869	N.A.	N.A.	650
1981	2911	90.2	2626	769
1980	2866	81.2	2327	791
1979	2948	87.1	2568	707
1978	3099	80.7	2501	768
1977	3143	79.3	2492	955
1976	3382	67.8	2293	956
1975	3416	76.2	2603	742
1970	3530	64.1	2263	700

* Projected

N.A. - Not Available

Sources:

"World Fertilizer Capacity," 3/26/84, TVA National Fertilizer Development Center, Muscle Shoals, Alabama.

Fertilizer Trends 1982, TVA National Fertilizer Development Center.

"Commercial Fertilizers - Consumption for Year Ended June 30, 1984," USDA Crop Reporting Board.

Fertilizer Reference Manual, June 1982, The Fertilizer Institute.

based on the date for commencement of construction.[3] A survey of the industry indicates no anticipated expansion or new construction of caprolactam by-product AS plants in the near future.[4,5,6]

There has been a decline in production in both the synthetic manufacture of ammonium sulfate and coke oven by-product AS since 1978, with plant closings in both segments of the industry. A telephone survey of synthetic AS producers confirms that most are operating well below design production capacities.

Ammonium sulfate's share of the fertilizer market has increasingly been displaced by other sources of higher analysis nitrogen fertilizers, such as anhydrous ammonia and urea. Ammonium sulfate is 20.9 percent nitrogen compared to 82 percent for anhydrous ammonia and 44.5 percent for urea. Ammonium sulfate will continue to be a leading source of plant nutrient sulfur in the U.S. fertilizer market, but there has been a notable increase in the use of other sulfur carriers, such as ammonium thiosulfate, rather than expanding supplies of AS.[7] Based on current capacity utilization, announced expansions, and consumption patterns, the likelihood of any significant growth of ammonium sulfate fertilizer manufacture in the next few years is nil.[4]

The Fertilizer Institute (TFI) reports an average operating rate for AS producers in 1983 at 71 percent of their total capacity, with the middle 50 percent of the plants falling between 39 and 72 percent.[7] This indicates that ample capacity is available in the U.S. to meet any future increased demands which may occur. There have been no plant modifications or reconstructions in the AS manufacturing industry which are subject to the NSPS.

The Clean Air Act Amendments of 1977 require that the EPA review the NSPS at least every 4 years to assess the need for possible revision of standards [Section 111(b)(1)(B)]. This report presents the results of the first review of the NSPS for ammonium sulfate. The review was conducted by examination of current ammonium sulfate literature, contacts with EPA Regional and State offices, contacts with producing plants, and contacts with fertilizer trade associations.

2.2 Background Information

The primary use of ammonium sulfate (>95%) is as an agricultural fertilizer. More than 50 percent of ammonium sulfate is generated as a by-product of caprolactam, which is used in the manufacture of nylon-6 fibers. Because a great percentage of AS is generated as a by-product of another process, production is not based solely on the demand for fertilizer, but more on the demand for primary products.

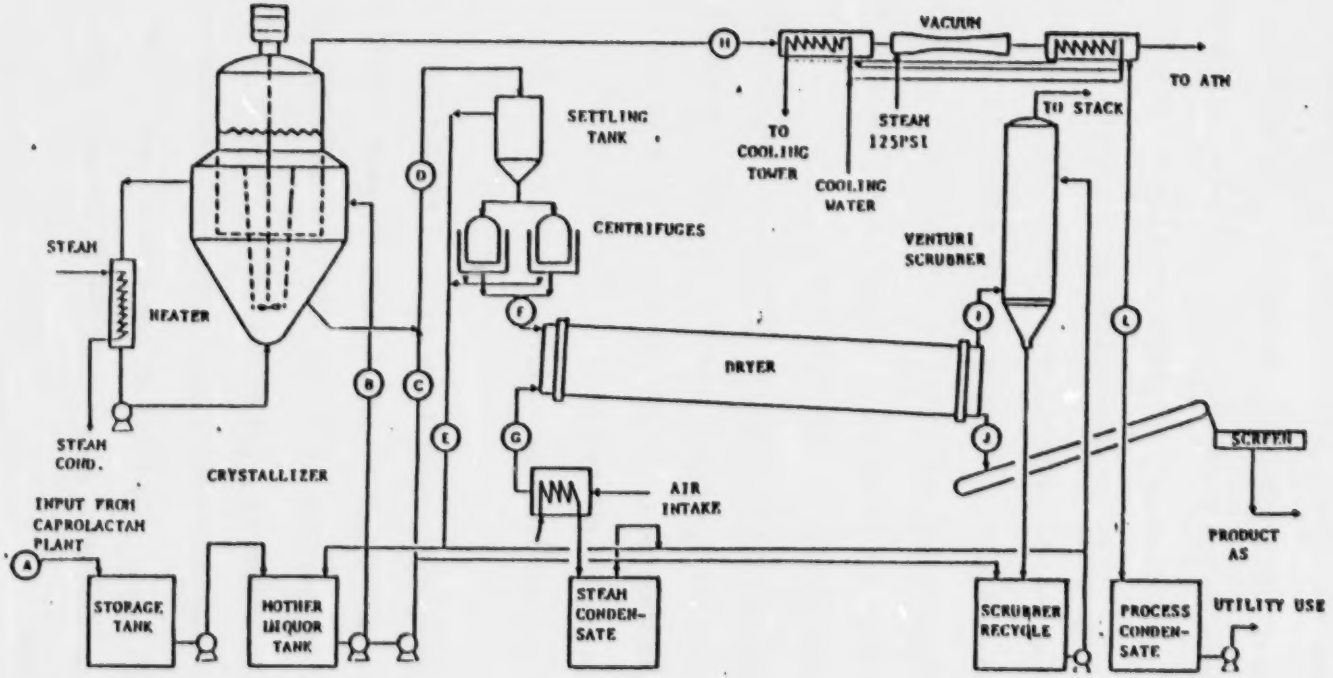
The ammonium sulfate dryer is the main source of particulate emissions in the production process. There are other sources of fugitive emissions such as crystallization, dewatering, screening, and materials handling, but they are not, in the opinion of EPA, significant emission sources.[8] Two types of dryers used in AS production are rotary dryers and fluidized bed dryers. Rotary dryers may be direct fired or steam heated, and fluidized bed dryers in the industry are all steam heated. Gas flow rates, heat transfer rates, and mass transfer rates are the important parameters for drying AS. These parameters may vary widely with different dryers in the industry.

2.3 Ammonium Sulfate Production

The three ammonium sulfate production processes covered by the NSPS are caprolactam by-product, coke oven by-product, and synthetic manufacture. The basic difference in the three production processes is the method of producing the AS crystals from the various feedstocks. From the step of crystallization onward, the three processes are quite similar. The slurry of crystals is dewatered by centrifugation, dried and screened (except in coke oven by-product processes where screening appears to be nonexistent), and the dryer exhaust gases are vented to the emission control equipment. The dried AS crystals are conveyed to storage, and fines separated by screening are recycled back to the crystallizer.

2.3.1 Caprolactam By-Product Ammonium Sulfate - A typical process flow diagram for caprolactam by-product ammonium sulfate is shown in Figure 2-1. It is based on information obtained from plant visits to the three caprolactam production plants and responses to EPA inquiries.[9] The material flow rates in Figure 2-1 are based on a typical AS production rate of 22.7 Mg/hr (25 ton/hr).

The ammonium sulfate crystals are produced by continuously heating and circulating a 40 percent AS mother liquor through a draft tube-baffle crystallizer at temperatures of 77° to 82°C (170° to 180°F) and at a pressure of about 660 mm Hg (12.8 psia). Water vapor is released from the crystallizer and condenses in one or more heat exchangers. The AS slurry, known as "magma" flows out of the crystallizer to the settling tank, where clear liquid is decanted as the AS crystals settle to the bottom of the tank.



Pounds/Hour

Line	A	B	C	D	E	F	G	H	I	J	K	L
Cryst AS	0	0	0	49,000	-	49,000	0	0	-	49,950	0	0
Liquid AS	50,000	102,000	30,500	83,300	82,300	1,000	0	0	-	0	4,100	0
Water	73,300	152,700	45,700	126,300	125,000	1,300	0	72,000	1,300	50	12,300	64,800
Total	123,300	254,700	76,200	258,600	207,300	51,300	0	72,000	1,300	50,000	16,400	64,800
Temp °F	AMB	AMB	200	150	115	120	300	-	175	175	150	-
Gas Flow	-	-	-	-	-	-	150,000	UK	150,000	-	-	-

Figure 2-1. CAPROLACTAM BY-PRODUCT AMMONIUM SULFATE PROCESS FLOW DIAGRAM

The slurry of ammonium sulfate crystals and mother liquor moves next to the centrifuge system, where a bulk separation is performed. Typical crystal throughput for a two centrifuge system varies from 8-11 Mg/hr (9-12 ton/hr) per centrifuge. A spare centrifuge is generally provided on stand-by in the event that lines become plugged with solid AS.

From the centrifuges, the AS crystals enter the dryer, which is the principal source of AS particulate emissions. Both rotary drum and fluidized bed dryers are used in the caprolactam industry. Typical operating parameters for a caprolactam by-product AS dryer are presented in Table 2-2.

Caprolactam, $(CH_2)_5$ CONH, is carried through the AS process stream in small quantities. Caprolactam has a melting point of 60°C (140°F) and a boiling point of 140°C (284°F), so any caprolactam present in the AS dryer at the operating temperatures involved, about 85°C (185°F), is in the liquid phase. This residual hydrocarbon coats the AS crystals and serves as an anti-caking agent in storage, circumventing the need for addition of other substances to prevent caking of the AS product. The majority of caprolactam is removed from the system in this manner.

From the dryer, ammonium sulfate crystals are conveyed to a screening area for separation and storage. The screening operation is typically carried out within a building, and a screen enclosure may be used to prevent fugitive emissions. The exhaust gases from the dryer are passed through a particulate collection device, usually a wet scrubber. Some screening operations are also equipped with scrubbers. Liquid waste streams from the collection device are recycled back into process streams, eliminating water pollution concerns and increasing production efficiencies.

TABLE 2-2. TYPICAL PARAMETERS FOR A CAPROLACTAM BY-PRODUCT AMMONIUM SULFATE DRYER

Parameter	Type/Value
Dryer	Rotary or fluidized bed
Product flow through dryer, Mg/hr (tons/hr)	23 (25)
Air flow through dryer, scm/min (scfm)	825 (29,200)
acm/min (acfm) @85°C (184°F)	1000 (35,500)
Air flow per ton of product, scm/Mg (scf/ton)	2152 (70,000)
Air temperature	
Inlet to dryer, °C (°F)	149 (300)
Outlet of dryer, °C (°F) (Inlet to scrubber)	85 (185)
Uncontrolled particulate emissions from dryer	
kg/Mg of product (lb/ton)	
Rotary dryer	26 (52)
FB dryer	111 (221)
AS product temperature and water content, wt. percent	
Dryer inlet 66°C (150°F)	2.0 - 2.5
Dryer outlet 80°C (175°F)	0.1 - 0.5
Water evaporated per ton of product, kg/Mg (lb/ton)	24 - 25 (48 - 50)
Steam input to dryer kg cal/hr (Btu/hr)	3,024,000
Sat 125 psig at 177°C (350°F)	(12,000,000)

2.3.2 Synthetic Ammonium Sulfate - Synthetic AS is produced by neutralizing concentrated sulfuric acid with pure ammonia in a crystallizer/reactor as indicated by the following chemical equation:

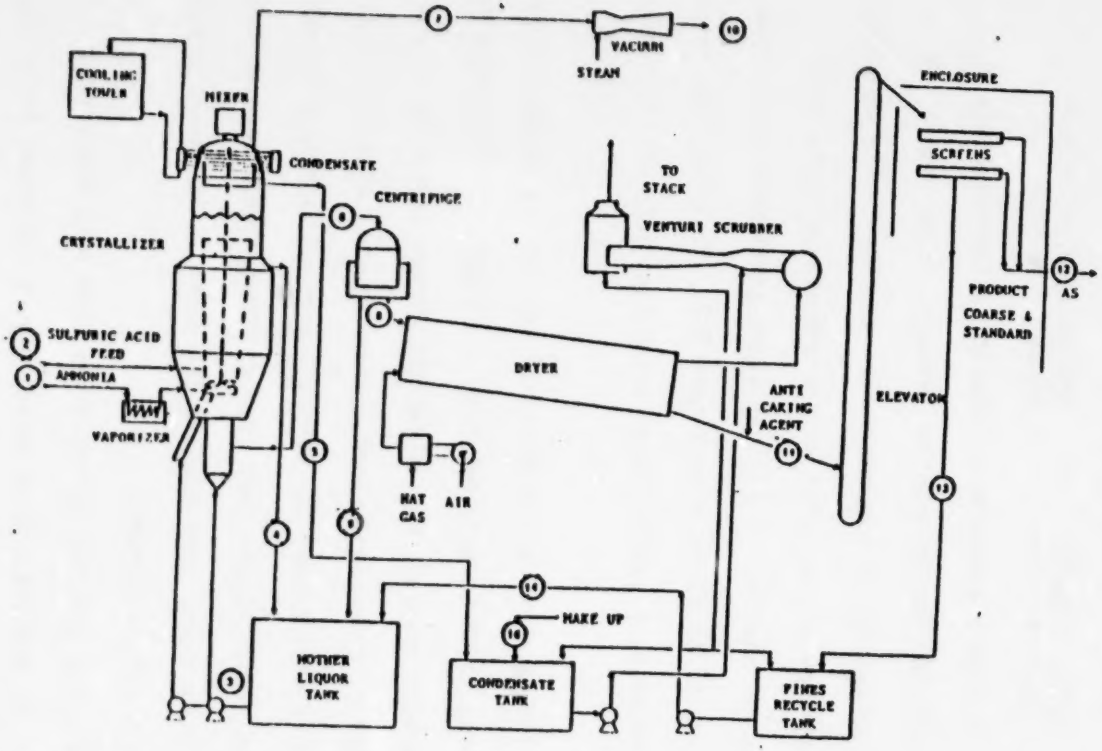
$$\underset{\text{Ammonia}}{2NH_3\ (gas)} + \underset{\text{Sulfuric acid}}{H_2SO_4\ (liquid)} \longrightarrow \underset{\text{Ammonium sulfate}}{(NH_4)_2SO_4(solid)} + \text{Heat}$$

This reaction is highly exothermic, liberating approximately 67,710 cal/g mole (120,000 Btu/lb mole) of product. Heat removal is achieved by a cooling section or external heat exchanger. The AS mother-liquor stream is injected at the point of the ammonia-sulfuric acid reaction to improve the cooling. A typical plant configuration for the synthetic manufacture of AS is shown in Figure 2-2. Material flow rates in Figure 2-2 are based on a typical dryer production rate of 13.7 Mg/hr (15 tons/hr).

The crystallizer may have an "elutriation leg" at the magma discharge. Mother liquor flowing in this leg blows back or "elutriates" the fine AS particles into the main chamber, but allows the larger particles to pass to the discharge point, producing a more uniform crystal size distribution.

The AS crystal slurry leaves the crystallizer and is pumped to one or more centrifuges, which remove most of the mother liquor and recirculate it back to the crystallizer. Upon leaving the centrifuges the AS crystals have a 1-2 percent moisture content.

The AS crystals are then fed to the dryer, the only significant emission source in the process. Only rotary dryers are known to be used in synthetic AS production plants. Operating parameters for the 13.7 Mg/hr (15 ton/hr) dryer in Figure 2-2 are shown in Table 2-3.



Base Bal: Pounds/Hour

Line	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NH_3	3,730															
H_2SO_4		22,270	9,800	9,000		800			800							
H_2O	80	450	550,000	493,000	14,000	40,000	3,600	700	39,300	630	70	63	7	17,700	5,400	3,700
Liq AS			570,000	529,200		37,200			32,200					3,630	54	
Cryst AS			11,000	11,000		33,600		33,600			33,600	30,000	3,600			
Total	3,810	22,270	1,140,000	1,042,200	14,000	111,600	3,600	34,300	72,300	630	33,670	30,063	3,607	21,330	5,454	3,700

Figure 2-2. SYNTHETIC AMMONIUM SULFATE PROCESS FLOW DIAGRAM

TABLE 2-3. TYPICAL PARAMETERS FOR A SYNTHETIC AMMONIUM SULFATE DRYER

Parameter	Type/Value
Dryer	Rotary, direct fired
Product flow through dryer, Mg/hr (ton/hr)	13.7 (15.0)
Air flow through dryer, scm/min (scfm) acm/min (acfm) @ 93°C (200°F)	135 (4750) 170 (5920)
Air flow per ton of product, scm/Mg (scf/ton)	591 (19,000)
Air temperature	
Inlet to dryer, °C (°F)	232 (450)
Outlet to dryer, °C (°F)	93 (200)
AS uncontrolled emission from the dryer, kg/Mg (lb/ton) of product	26 (52)
Product temperature and water content percent	
Dryer inlet - 88°C (190°F)	2.0 - 2.5
Dryer outlet - 93°C (200°F)	0.1 - 0.5
Water evaporated, kg/Mg (lb/ton)	24 - 25 (48 - 50)

Screening of the AS divides a coarse and a standard product. As in caprolactam by-product manufacture, screening takes place inside a storage building, and fugitive dust is minimal. Synthetic plants may add a small quantity of heavy hydrocarbon to the product to prevent caking.

2.3.3 Coke Oven By-Product AS - In the carbonization of coal into coke, many volatile substances are liberated. At a temperature of 1000°C (1832°F), which is common in steelmaking, the liberation of ammonia in the off-gases is optimized. Formation of ammonium sulfate is traditionally the most common method for the recovery of the ammonia off-gases from the coking process. This is accomplished by one of three different methods, which are classified according to the means of contacting the ammonia with sulfuric acid. These are the direct, indirect, and semidirect processes. Most of the ammonia produced in coke plants is recovered as ammonium sulfate by the semidirect process. The balance is produced in the form of concentrated ammonia liquors by the indirect process. The direct process also recovers ammonia directly as AS, but this process is not used in the U.S.[10]

In the semidirect process the off-gases are cooled and washed to remove tar and yield an aqueous condensate high in ammonia content. The ammonia is released from the condensate in a still. It is then combined with the main gas stream, reheated to approximately 21°C (70°F), and scrubbed with a dilute (5 to 6 percent) sulfuric acid solution. Ammonium sulfate crystals of high purity are formed and removed as product.

The indirect process recovers ammonia from the coking off-gases as a dilute ammonia liquor, from which ammonia is stripped and converted to a concentrated liquor. The dilute liquor is treated with steam in a stripping column to release free ammonia present in salts such as ammonium carbonate and ammonium sulfide. The liquor is then treated with lime to decompose fixed salts such as ammonium chloride, after which it passes to a second stripping column where the remaining ammonia is released. This ammonia is recovered in a more concentrated liquor and can be converted directly to a solid in a crystallizer.

In the direct process the off-gases are first cooled for maximum removal of tar, and are then passed through the crystallizer/saturator where they are washed with sulfuric acid. The AS crystals that form in the liquor are recirculated until the desired crystal size is attained. There are problems associated with the direct process, such as deposition of tar in the saturator and decomposition of ammonium chloride carried by the gas to form hydrochloric acid, creating corrosion problems.

Figure 2-3 shows a schematic of the coke oven by-product ammonium sulfate process. The reaction between ammonia and sulfuric acid is exothermic, and a large portion of the generated heat is used in evaporating water from the sulfuric acid bath. Approximately 1 kg of 77.8 percent H_2SO_4 is consumed per kg of AS produced.[11] The AS crystals precipitate and are pumped in a slurry to the centrifuges for removal of liquids. The crystals are then conveyed to a dryer, where the moisture content is

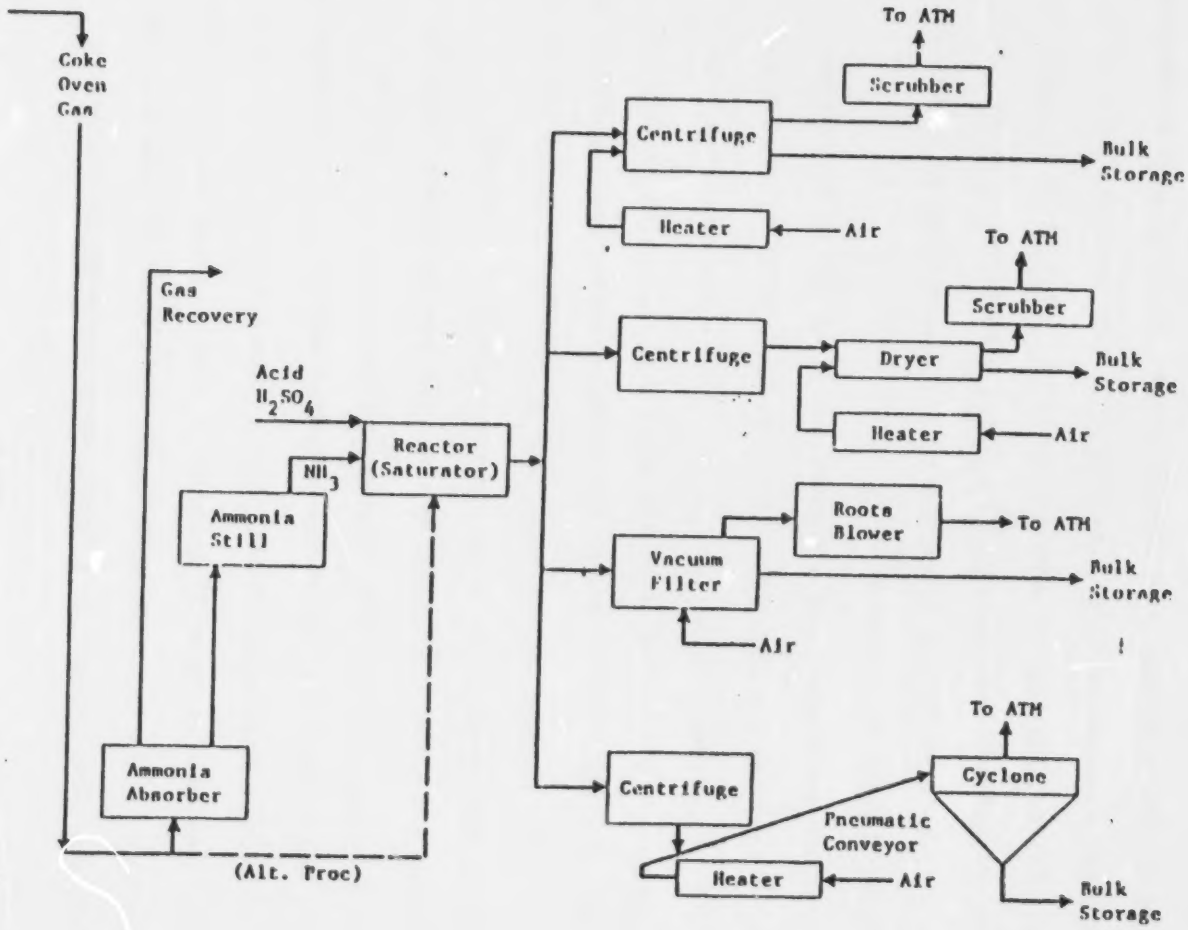


Figure 2-3. PROCESS FLOW DIAGRAM FOR COKE OVEN AMMONIUM SULFATE PLANTS SHOWING ALTERNATE DRYING PROCESSES

reduced to about 0.15 percent and sent to storage. In coke oven by-product AS a small amount of gypsum may be added to prevent caking. Gypsum preferentially combines with moisture from the atmosphere.

Dewatering equipment varies in each plant, and may include vacuum filters, centrifuges, and dryers in more than one combination. Mother liquor from the dewatering and drying processes is recycled back into the process stream. Table 2-4 lists operating parameters for a typical coke oven AS dryer.

Two U.S. facilities have adopted Nippon Steel's TAKAHAX process for coke oven gas desulfurization (COGD), of which AS is a by-product. The process changes were exempt from the NSPS based on the date for commencement of construction. Only one of the two plants is currently in operation. A slip stream from this process, rich in sulfur salts, constitutes the AS feed stream. Variations in the process may use sodium carbonate or caustic soda as the alkali in place of ammonia. In either case, the end product is sulfuric acid or elemental sulfur, respectively, instead of AS. The facility currently in operation produces AS as the end product.[12]

TABLE 2-4. ESTIMATED PARAMETERS FOR A COKE OVEN BY-PRODUCT AMMONIUM SULFATE DRYER

Parameter	Type/Value
Dryer	Rotary vac. filter-dryer, centrifuge-dryer or rotary dryer
Product flow through dryer, Mg/hr (ton/hr)	2.7 (3.0)
Air flow through dryer, scm/min (scfm)	99 (3,500)
Air mass flow assumed per ton product scm/Mg (scf/ton)	2203 (70,000)
Air temperature	
Inlet to dryer, °C (°F)	149 (300)
Outlet to dryer, °C (°F)	80 (175)
AS uncontrolled emission from the dryer, kg/Mg of product (lb/ton)	10.0 (20.0)[a]
Product temperature and water content percent	
Dryer inlet - 49°C (120°F)	2.5
Dryer outlet - 66°C (150°F)	0.5
Water evaporated, kg/Mg (lb/ton)	20 (40)
Steam heat input to dryer, kg cal/hr (Btu/hr)	163,800 (650,000)

[a] Estimated based on 1 percent of AS product appearing as uncontrolled dryer emissions.

2.4 References

1. Fertilizer Reference Manual, June 1982. Published by the Fertilizer Institute.

2. Commercial Fertilizers - Consumption for Year ended June 30, 1983, USDA Crop Reporting Board.

3. Information provided in a letter from F. L. Piguet, Allied Fibers and Plastics, to Jack Farmer, U.S. Environmental Protection Agency, Research Triangle Park, N.C., dated August 2, 1984.

4. Information provided in a letter from Karl T. Johnson, The Fertilizer Institute, to Peter Schindler, U.S. EPA, dated June 8, 1984.

5. Information provided in telephone conversation by Max Beal, Nipro, Inc., to Peter Schindler, U.S. EPA, on June 18, 1984.

6. Information provided in telephone conversation by E. Harre, TVA National Fertilizer Development Center, to Peter Schindler, U.S. EPA, on May 30, 1984.

7. Information provided in a letter from Edwin A. Harre, TVA National Fertilizer Development Center, to Naum Georgieff, U.S. Environmental Protection Agency, Research Triangle Park, N.C., dated June 7, 1984.

8. Ammonium Sulfate Manufacture - Background Information for Proposed Emission Standards, EPA-450/3-79-034a, p. 9-3.

9. Reports of plant trips to: The Allied Chemical Company, Hopewell, Va; NIPRO Inc., Augusta, GA; Dow Badische Company, Freeport, TX; regarding ammonium sulfate plant emission standards development. Docket No. A-79-31.

10. Coal, Coke, & Coal Chemicals, p. 290, copy provided with letter from John Stavik, Dravo/Still, to Naum Georgieff, U.S. EPA, dated July 11, 1984.

11. Reference 10, p. 297.

12. Information provided in letter and enclosures from R. F. Wyse, U.S. Steel, to Peter Schindler, U.S. Environmental Protection Agency, dated July 27, 1984.

3. CURRENT STANDARDS FOR AMMONIUM SULFATE PLANTS

3.1 Affected Facilities

The NSPS regulates newly constructed, reconstructed, and modified ammonium sulfate plants that produce AS as a caprolactam by-product, as a coke oven by-product, or by the synthetic process (direct combination of ammonia and sulfuric acid.) Each ammonium sulfate dryer is the affected facility.

An existing ammonium sulfate plant may be subject to the NSPS if: (1) it is modified by a physical or operational change in an existing facility thereby causing an increase in the emission rate to the atmosphere of particulate matter, or (2) if in the course of reconstruction of the facility, the fixed capital cost of the new components exceeds 50 percent of the cost that would be required to construct a comparable entirely new facility that meets the NSPS.

3.2 Controlled Pollutants and Emission Levels

Particulate matter is the pollutant regulated by the NSPS, and dryer emissions are limited to not more than 0.15 kg of particulate matter per Mg (0.30 lb/ton) of AS produced. Visible emissions are limited to not more than 15 percent opacity.

3.3. Monitoring Requirements

The promulgated standards require continuous monitoring of the mass flow of ammonium sulfate feed material to the crystallizer. Those facilities with weigh scales are exempt from this requirement. The feed stream in a

caprolactam plant is the oximation AS stream to the AS plant and the oleum stream to the caprolactam rearrangement reaction. The feed stream in synthetic and coke oven by-product plants is the sulfuric acid stream to the crystallizer.

Another requirement of the standard is continuous monitoring of the pressure drop across the control system for the affected facility to help insure proper operation and maintenance of the system. Mass flow and pressure drop data, including calibration measurements of the instrumentation, must be maintained for 2 years by the affected facility.

There is no in-stack opacity monitoring requirement due to the use of wet scrubbing in most AS particulate control applications. The presence of water droplets in the stack would make the exhaust gases difficult to monitor by available equipment.

3.4. Testing Requirements

The EPA Reference Methods (40 CFR 60, Appendix A) to be used in conjunction with compliance testing of AS dryers include:

1. Method 5 for the concentration of particulate matter.
2. Method 1 for sample and velocity traverses.
3. Method 2 for velocity and volumetric flow rate.
4. Method 3 for gas analysis.

For Method 5, the sampling time for each run shall be 60 minutes minimum, and the volume shall be at least 1.50 dry standard cubic meters (53 dry standard cubic feet). Methods for computing particulate emission rates and AS production rates are contained in 40 CFR 60, Subpart PP.

4. STATUS OF CONTROL TECHNOLOGY

4.1 Emission Sources

The ammonium sulfate dryer is the main source of particulate emissions in the AS manufacturing process, and the only source which is regulated by the NSPS. Both fluidized bed dryers and rotary dryers are used in AS producing facilities. All fluidized bed dryers found in the industry are heated indirectly with steam-heated air. Rotary dryers may be either direct fired (by oil or gas) or steam heated.

Gas flow rates are higher for steam heated dryers--typically 2200 scm/Mg of product (70,000 scf/ton), than for direct fired units--600 scm/Mg (20,000 scf/ton). Fluidized bed dryers have demonstrated higher rates of uncontrolled emissions, largely due to fines being swept out of the system. Because this characteristic creates a more granular, salable product, fluidized bed dryers are more desirable from a production standpoint. Fluidized bed dryers exhibit greater heat and mass transfer rates, and smaller space requirements than rotary dryers with the same throughput. Capital and operating costs are also less for fluidized bed dryers, making them more economically desirable.[1] Fluidized bed dryers, however, would require more efficient particulate control equipment in order to comply with air pollution regulations, as the emission rates per ton of product are greater.

Table 4-1 contains a summary of uncontrolled particulate emissions from several dryers in the industry that were tested using EPA Method 5.[2] The wide range of uncontrolled emissions (expressed as mass of particulate emissions per mass of product) is a result of the various flow rates for differing

TABLE 4-1. SUMMARY OF UNCONTROLLED EMISSION DATA FROM EPA EMISSION TESTS ON AS DRYERS

Plant	Dryer Type	Average Uncontrolled AS Emissions			
		gm/dscm	(gr/dscf)	kg/Mg	(lb/ton)
A	Rotary Drum	4.38	(1.93)	0.41	(0.82)
B	Fluidized Bed	39.0	(17.2)	110.0	(221.0)
C	Rotary Drum	8.87	(3.91)	3.46	(6.92)
D	Rotary Drum	98.3	(43.2)	77.0	(153.0)

dryer systems. The high rotary dryer emission rate at Plant D was attributed to a high inlet emission load caused by a process variation at the plant. It was indicated that the crystallizer at Plant D periodically goes into a fines cycle, lasting anywhere from 10 to 15 hours, during which time a much heavier proportion of AS fines is produced in the dryer product than is normal.[3] Plant personnel stated that the operator can prevent this condition by varying the dryer air flow rate, but this was not done during testing so as to maintain constant operating conditions. Particulate emission rates are directly related to the gas-to-product ratio, and are influenced by gas velocity and particle size distribution. No additional data on uncontrolled emissions from AS dryers have become available since promulgation of the NSPS.

4.2 Emission Control Equipment in the Ammonium Sulfate Industry

There have been no major changes in control technology since promulgation of the ammonium sulfate NSPS. Wet scrubbing is used at all of the operating ammonium sulfate facilities for the control of AS dryer particulate emissions. The use of wet scrubbing is for environmental reasons, as well as to increase production efficiencies. Wet control processes allow easy recycle of captured AS particles back into process streams, increasing production efficiency and eliminating the cost of waste disposal. The moderately high water solubility of AS makes wet scrubbing and recycle of captured particulates a viable control alternative. Industry supplied operating and performance data for a number of wet scrubbers in use is presented in Table 4-2. Most of the scrubbers are of the low energy type with pressure drops equal to or less than 15 cm

TABLE 4-2. AMMONIUM SULFATE INDUSTRY-SUPPLIED WET SCRUBBER PERFORMANCE DATA[a]

	Scrubber Vendor	AS Scrubber Type	AS Production Rate Mg/hr (TPH)	Gas Flow to Scrubber sm^3/min (scfm)	Observed Scrubber Pressure Drop cm H_2O WC (in H_2O WC)	Scrubber L/G Ratio[g] Liters/1000m^3 (gal/1000 acf)
Plant F	Ducon	Centrifugal	----	----	7.6 (3)	254 (1.9)
	AAF[b]	Rotocloned	----	----	12.7 (5)	348 (2.6)
	AAF	Rotoclone	----	----	12.7 (5)	415 (3.1)
Plant E	Ducon	Centrifugal[e]	----	1,127 (39,900)	34.0 (13.4)	267 (2.0)
	Ducon	Centrifugal	----	410 (14,600)	22.9 (9.0)	267 (2.0)
Plant B	----	Venturi	----	810 (28,600)	25.9 (10.2)	3,075 (23.0)
Plant H	NA[c]	Spray	19.1 (21)	144 (5,100)	17.3 (6.8)	909 (6.8)
Plant G	NA	Packed Tower & NH_3 Condenser	19.1 (21)	242 (8,560)	UK[f]	3,338 (25.0) 40,050 (300)
Plant I	NA	Packed Tower	14.7 (16)	73 (2,585)	UK	2,311 (17.3)
Plant C	Ducon	Centrifugal	8.50 (9.34)	90 (3,180)	15.2 (6)	267 (2.0)
	Ducon	Centrifugal	16.2 (17.8)	112 (3,950)	15.2 (6)	267 (2.0)
Plant D	Heil	Venturi	8.4 (9.2)	85 (3,000)	33.0 (13)	3,605 (26.9)

a All data supplied by industry in response to EPA 114 letter requests or from visits to AS production plants.
b American Air Filter.
c Not Applicable (not a standard design).
d Trade name of American Air Filter Company.
e Cyclones precede centrifugal scrubbers.
f Unknown.
g Scrubber liquid-to-gas ratio.

TABLE 4-2. (cont) AMMONIUM SULFATE INDUSTRY-SUPPLIED WET SCRUBBER PERFORMANCE DATA

	AS Particulate Concentration		AS Mass Flow		AS Mass
	Scrubber Inlet mg/dsm^3 (gr/dscf)	Scrubber Outlet mg/dsm^3 (gr/dscf)	Scrubber Inlet kg/hr (lb/hr)	Scrubber Outlet kg/hr (lb/hr)	Discharge Rate kg/Mg (lb/ton
Plant F	----	220 (.096)	----	----	.13 (.25)
	----	57.2 (.025)	----	----	.032 (.065)
	----	708 (.309)	----	----	.36 (.72)
Plant E	----	87 (.038)	----	5.6 (12.4)	.26 (.52)
	----	48 (.021)	----	1.2 (2.67)	.14 (.27)
Plant B	28,500 (12.4)	11.5 (.005)	1,909 (4,200)	.45 (1.0)	.037 (.073)
Plant H	----	25.2 (.011)	----	.22 (.48)	.012 (.023)
Plant G	----	9.2 (.004)	----	.14 (.30)	.007 (.014)
Plant I	----	41.2 (.018)	----	.23 (.50)	.016 (.031)
Plant C	----	48.1 (.021)	----	.254 (.56)	.030 (.06)
		36.7 (.016)	----	.25 (.55)	.015 (.031)
Plant D	----	----	----	----	----

(6 in.) WG. The data contained in Table 4-2 were provided by AS producers during EPA plant visits and in responses to EPA inquiries during development of the NSPS in 1978-79, and do not reflect any equipment modifications which may have occurred since that time.

4.2.1 Venturi Scrubbers - Two existing AS plants employ venturi scrubbers to control particulate emissions. Pressure drops and liquid-to-gas ratios are similar for both of these control devices. Performance data and emission test data for the venturi scrubber at Plant B are included in Table 4-2. No emission test data were supplied for the venturi scrubber at Plant D. Based on test measurements of the scrubber inlet and outlet mass flows, the venturi at Plant B has an average collection efficiency of 99.96 percent, which is typical of venturi scrubbers in other applications. Particulate emissions average .037 kg/Mg of AS production. A 25 percent AS solution was used as the scrubbing liquid, and although the emission test was conducted at approximately 50 percent of the maximum production rate, the collection efficiencies are similar to those measured during a period of full capacity production.[4]

4.2.2 Centrifugal Scrubbers - Centrifugal scrubbers are employed at a number of AS plants for particulate control, including two of the three existing caprolactam plants. Energy requirements and collection efficiencies of centrifugal scrubbers are generally lower than those of venturis. Emission test data for centrifugal scrubbers at Plants C, E, and F are provided in Table 4-2. Pressure drops range from 7.6 cm to 34.0 cm WG (3 to 13.4 in. WG),

and mass emissions vary from 0.015 to 0.26 kg/Mg (0.031 to 0.52 lb/ton) of AS production. No centrifugal scrubber inlet data are available, and collection efficiencies cannot be determined.

4.2.3 Other Wet Scrubbers in the AS Industry - Several other wet scrubbing systems currently in use for AS particulate control include packed tower scrubbers, spray type scrubbers, and Type "N" Rotoclones (a trade name of American Air Filter Corporation). Particulate control data for each of these control devices are presented in Table 4-2 (Plants H, G, and I). Collection efficiencies of these devices are generally lower than those of previously mentioned AS particulate control devices. Vendor design efficiency data for Rotoclones typically ranges from 90 to 99.3 percent for particulates 3 microns in diameter, with pressure drops of 15.3 to 28 cm (6 to 11 in.) WG and high liquid-to-gas ratios.[5] Collection efficiencies of packed towers depend on liquid-to-gas ratios and pressure drops. One plant which designed its own packed tower reports an estimated collection efficiency of less than 90 percent.[5] Spray-type scrubbers demonstrate collection efficiencies near 75 percent for most types of 2 micron particulates. Pressure drops are low, usually 2.5 cm to 5 cm (1-2 in.) WG.[6]

4.2.4 Fabric Filtration in the Ammonium Sulfate Industry

Only one known domestic producer of AS has used a baghouse for AS particulate control, but this plant has been mothballed since 1979.[7] The unit has 30m^2 (320 ft^2) of filter cloth which comprises 24 bags, and it employs a reverse jet cleaning mechanism. The filter medium is Dacron® felt, which exhibits good acid resistance and flex abrasion. At the operating gas flow rate of approximately 35m^3/min (1250 acfm) the gas-to-cloth ratio of this baghouse is 4:1.

Fabric filters are adversely affected if condensation occurs in the baghouse, and this is especially true in ammonium sulfate particulate control. Caking of AS particles due to condensation may cause blinding in fabric filters. It is imperative that the exhaust gas be maintained at a temperature above the dew point to avoid this problem. This is the major drawback in employing fabric filters for AS particulate control. Evidence of condensation problems at the existing baghouse has been confirmed by AS accumulations on the inside wall of the inlet ducts, and periodic shutdown for bag removal, laundering, and reinstallation (every 30 days). It is possible that energy requirements for maintaining temperatures above the dew point may require more energy than would ordinarily be required to operate the dryer.[8]

4.3 Plant Testing

During the development of the existing NSPS for ammonium sulfate plants a survey of producing facilities determined that very few met the criteria for AS particulate emission testing to support an NSPS. These criteria included:

- Candidate best demonstrated control technology in operation
- Accessibility of potential control equipment sampling ports
- Control equipment age and/or condition
- Availability of sampling ports and support scaffolding
- Reasonably nonturbulent flow field
- Representative plant capacity

Four AS producing facilities were selected which met the criteria for testing, and emissions testing was carried out by EPA contractors at each facility, designated A through D. EPA Method 5 was used to determine AS particulate

emission rates and grain loadings at the inlet and outlet of each control device. Table 4-3 describes the selected test facilities, type of AS production process employed, and control technology in use. Plant E was not tested by EPA; information was provided by a State Agency, and the test methodology was judged acceptable by EPA.

TABLE 4-3. AS PARTICULATE CONTROL SYSTEMS TESTED BY EPA

Plant Designation	AS Process	Controlled Facility	Control Technology In Use
A	Synthetic	Rotary Dryer	Baghouse
B	Caprolactam	Fluid Bed Dryer	Venturi Scrubber
C	Synthetic	Rotary Dryer	Centrifugal Scrubber
D	Synthetic	Rotary Dryer	Venturi Scrubber
E	Caprolactam	Fluid Bed Dryer	Cyclones and Centrifugal Scrubber

Results of EPA emission testing at facilities A through D are summarized in Table 4-4, along with the industry-supplied emission data from Plant E. The wide range of uncontrolled emission data represents the varying process rates for AS drying equipment encountered in the industry. Lower particulate removal efficiencies at Plants A and C can be attributed partially to lower uncontrolled dryer emission rates at these respective facilities. With differences in uncontrolled emission rates at Plants A and C near two orders of magnitude as compared with those of Plants B and D, comparison of outlet mass emissions only for all four facilities may be somewhat misleading.

TABLE 4-4. RESULTS OF EPA EMISSION TESTING

Plant Designation	AS Production Rate (Mg/hr)	Average Uncontrolled Emission Rate (kg/Mg)	Average Controlled Emission Rate (kg/Mg)	Particulate Removal Efficiency (%)
A	16.4	0.41	.007	98.3
B	26.5	110.0	.156	99.9
C	15.2	3.46	.08	97.7
D	8.4	77.0	.14	99.8
E	8.9	N.A.*	.14	N.A.

* Not Available

4.5 References

1. Ammonium Sulfate Manufacture - Background Information for Proposed Emission Standard, EPA-450/3-79-034a, p. 3-10.

2. Reference 1, p. 3-11.

3. Reference 1, p. 9-12.

4. Reference 1, p. 4-10.

5. Reference 1, p. 4-12.

6. Reference 1, p. 4-13.

7. Information provided by Occidental Chemical Corporation in a telephone conversation between Russ Bowman and Peter Schindler, U.S. Environmental Protection Agency, Research Triangle Park, N.C., on July 13, 1984.

8. Reference 1, p. 4-15.

5. COMPLIANCE TEST RESULTS

Since proposal and promulgation of the NSPS, there have been no new, reconstructed, or modified facilities which have come under the NSPS. Emission testing, however, has been performed at some existing facilities, and testing results have been obtained by EPA.

A second State-approved emission test was performed at Plant E by a contractor to the company and the State has provided the test results to EPA.[1] The test results are contained in Table 5-1, and are well below the NSPS requirements, at .04 kg/Mg of AS production. This facility operates one rotary dryer and one fluidized bed dryer. The exhaust air from both dryers is combined and treated in a series of fines removal cyclones before it is redistributed to two wet scrubbers. The scrubbers, a Ducon type UW-3 size 126 and a Ducon type UW-3 size 72, are of the centrifugal type, and air flows are 1250 m^3/min (44,000 acfm) and 450 m^3/min (16,000 acfm), respectively. The scrubbers discharge to the atmosphere through separate stacks at about 80 feet above the ground. The emission test data provided by the State was for the size 72 scrubber, which is the smaller of the two, and the newer control device.[2]

In response to a written request from EPA, emission data have been provided from a caprolactam by-product AS plant, designated Plant J. This plant expanded AS production capacity in 1980, but the expansion is not subject to NSPS based on the date for commencement of construction. The plant controls particulate emissions from rotary dryers, centrifuges, and fugitive sources by the use of wet scrubbers. Two scrubbers were replaced recently, one handling centrifuge emissions (1979) and the other treating rotary dryer emissions (1980). Both new units are Ducon UW-4 scrubbers,

size 42 and 66, respectively, and operating efficiencies are reported to be 99 percent for each. The centrifuge abatement reduced AS particulate emissions from 14.6 Mg/yr to 5.1 Mg/yr, though this emission source is not subject to NSPS. The scrubbing liquor for all dust collectors at this plant is a recirculated oxime sulfate solution with a 10 gpm liquid rate per scrubber. Emissions testing was performed for the rotary dryer and new scrubber addition as part of the State permitting process, and emission results were 0.021 kg/Mg AS produced.[3] Test results for this dryer at Plant J, designated dryer #4, are presented in Table 5-1. Additional controlled emissions data for three other rotary dryers at Plant J are included in Table 5-1. Dryers #1, #2, and #3 were tested in conjunction with the State's Prevention of Significant Deterioration (PSD) program. Dryer #1 was tested in November 1980, and #2 and #3 were tested in December 1983.[4] The reported emission data from Table 5-1 indicates that the NSPS for ammonium sulfate particulate matter (.15 kg/Mg AS produced) is being easily achieved by current control methods.

TABLE 5-1. INDUSTRY SUPPLIED EMISSION TEST DATA

Plant Designation	Controlled Facility	Control Equipment	Production Rate (Mg/hr)	Air Flow Rate (DSCM/min)	Controlled Emission Rate (kg/Mg)
E	1 Rotary & 1 FB (dryer-stream combined)	Centrif. Scrubber (CS)	9.85	421.7	0.04
J #1	Rotary Dryer	CS	44.5	215.9	0.031
#2	Rotary Dryer	CS	36.4	221.8	0.053
#3	Rotary Dryer	CS	81.8	359.4	0.090
#4	Rotary Dryer	CS	52.7	196.3	0.021

5.1 References

1. Letter from Lou Musgrove, State of Georgia, Department of Natural Resources, Environmental Protection Division, to Peter Schindler, U.S. Environmental Protection Agency, Research Triangle Park, N.C., dated June 11, 1984.

2. Information provided in a telephone conversation between Lou Musgrove, State of Georgia EPD, and Peter Schindler, U.S. EPA, on October 9, 1984.

3. Letter from F. L. Piguet, Allied Fibers & Plastics, to Jack Farmer, U.S. Environmental Protection Agency, Research Triangle Park, N.C., dated August 2, 1984.

4. Information provided in a telephone conversation between Evans Drake, Allied Fibers and Plastics, and Peter Schindler, U.S. EPA, on October 5, 1984.

6. COST ANALYSIS

This chapter presents the updated costs of a control system required to best achieve the current NSPS for ammonium sulfate particulate matter. Venturi scrubbers are the selected control systems for cost analysis in the three segments of the AS industry, as they represent best demonstrated control technology (BDCT). Capital and annualized costs of venturi scrubbers are estimated for three new model AS plants; a 22.7 Mg (25 ton) per hour caprolactam by-product plant, a 13.6 Mg (15 ton) per hour synthetic plant, and a 2.7 Mg (3 ton) per hour coke oven by-product plant. All costs are presented in March 1984 dollars and are considered to be accurate to ± 30 percent.

The control system includes all the equipment and auxiliaries required to provide the specified emission control. The capital cost of a control system includes all the cost items necessary to design, purchase, install, and commission the control system. In addition to the direct costs, the capital cost includes such indirect items as engineering, contractor's fee, construction expense, and a contingency.

The annualized cost represents the cost of owning and operating the control system. The operating cost covers the utilities, supplies, and labor required to operate and maintain the system on a day-to-day basis. The cost of owning the system includes capital-related charges such as capital recovery, property taxes, insurance, and administrative charges.

6.1 Capital Costs

The capital costs for a venturi scrubbing system are estimated for three model plants, representing each segment of the AS industry. Cost breakdowns for each model plant are presented in Tables 6-1 through 6-3.

TABLE 6-1. CAPITAL COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM[a]
(Caprolactam By-Product Plant with 22.7 Mg/hr Capacity)

Description	Cost (10^3 dollars)
A. Direct Costs	
1. Scrubber, fan and auxiliaries (C)	113.3
2. Instruments and controls (10% of C)	11.3
3. Taxes (3% of C)	3.4
4. Freight (5% of C)	5.7
Base Price (B)	133.7
5. Installation[b] (56% of B)	74.9
Total Direct Costs (TDC)	208.6
B. Indirect Costs	
1. Engineering and supervision (10% of B)	13.4
2. Construction and field (10% of B)	13.4
3. Construction Fee (10% of B)	13.4
4. Start-up (1% of B)	1.3
5. Performance Test (1% of B)	1.3
6. Contingencies (3% of B)	4.0
Total Indirect Cost (TIC)	46.8
Total Capital Cost	255.4

[a] March 1984 dollars.

[b] Includes factors for foundations and supports, handling and erection, piping, electrical, insulation, and paint. Does not include costs for site preparation, facilities, and buildings.

Source: " Estimating Air Pollution Control Costs," Part II, Table I.

TABLE 6-2. CAPITAL COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM[a]
(Synthetic Plant with 13.6 Mg/hr Capacity)

Description	Cost (10^3 dollars)
A. Direct Costs	
1. Scrubber, fan and auxiliaries (C)	45.9
2. Instruments and controls (10% of C)	4.6
3. Taxes (3% of C)	1.4
4. Freight (5% of C)	2.3
Base Price (B)	54.2
5. Installation[b] (56% of B)	30.4
Total Direct Costs (TDC)	84.6
B. Indirect Costs	
1. Engineering and supervision (10% of B)	5.4
2. Construction and field (10% of B)	5.4
3. Construction Fee (10% of B)	5.4
4. Start-up (1% of B)	0.5
5. Performance Test (1% of B)	0.5
6. Contingencies (3% of B)	1.6
Total Indirect Cost (TIC)	18.8
Total Capital Cost	103.4

[a] March 1984 dollars.

[b] Includes factors for foundations and supports, handling and erection, piping, electrical, insulation, and paint. Does not include costs for site preparation, facilities, and buildings.

Source: "Estimating Air Pollution Control Costs," Part II, Table I.

TABLE 6-3. CAPITAL COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM[a]
(Coke Oven By-Product Plant with 2.7 Mg/hr Capacity)

Description	Cost (10^3 dollars)
A. Direct Costs	
1. Scrubber, fan and auxiliaries (C)	40.6
2. Instruments and controls (10% of C)	4.1
3. Taxes (3% of C)	1.2
4. Freight (5% of C)	2.0
Base Price (B)	47.9
5. Installation[b] (56% of B)	26.8
Total Direct Costs (TDC)	74.7
B. Indirect Costs	
1. Engineering and supervision (10% of B)	4.8
2. Construction and field (10% of B)	4.8
3. Construction Fee (10% of B)	4.8
4. Start-up (1% of B)	.5
5. Performance Test (1% of B)	.5
6. Contingencies (3% of B)	1.4
Total Indirect Cost (TIC)	16.8
Total Capital Cost	91.5

[a] March 1984 dollars.

[b] Includes factors for foundations and supports, handling and erection, piping, electrical, insulation, and paint. Does not include costs for site preparation, facilities, and buildings.

Source: "Estimating Air Pollution Control Costs," Part II, Table I.

The methods for determining representative capital costs are described in the EPA publication "Estimating Air Pollution Control Costs," May 1984. This publication is a compilation of 18 articles on air pollution control cost estimating which appeared in Chemical Engineering magazine from October 6, 1980 to April 30, 1984. All costs in this study were updated to March 1984 dollars by the Chemical Engineering Plant Cost Index for fabricated equipment. The operating parameters for the venturi system used in this cost study are presented in Table 6-4. The venturi scrubber is evaluated for three different air flow rates, typical of the dryers in each AS industry segment. Volumetric flow rate, pressure drop, and materials of construction are the main variables for determining venturi scrubber capital costs.

6.2 Annualized Costs

In the ammonium sulfate industry the annualized cost of operating a particulate control device is a function of the number of hours the dryer operates per year. This value determines operating costs such as labor, utilities, and overhead. In this study, AS dryers are assumed to operate at the following rates: 8,400 hours/year for caprolactam by-product plants, 5,400 hours/year for synthetic plants, and 7,400 hour/year for coke oven by-product plants. Annualized costs and cost factors are calculated from current labor prices and from Part II of "Estimating Air Pollution Control Costs," and are updated to March 1984 dollars.

Annualized cost breakdowns for venturi scrubbers in each of the three regulated AS industry segments are presented in Tables 6-5 through 6-7. Credits for recovery of AS dryer emissions by venturi scrubbers help to

TABLE 6.4 VENTURI SCRUBBER OPERATING PARAMETERS

A. Pressure drop: 30.5 cm (12 in) H_2O

B. Liquid-to-gas ratio: 0.33 $m^3/100m^3$ (25 $gal/10^3$ ft^3)

C. Operating temperatures

   1. Inlet: 79°C (175°F)

   2. Outlet: 43°C (110°F)

D. Construction materials: fiberglass lined carbon steel

E. Fan

   1. Location: between dryer and venturi

   2. Materials: 304 SS

   3. Head pressure: 38.1 cm (15 in) H_2O @ 21°C, 1 atm

   4. Type: radial tip

F. Average venturi life: 10 yr

G. Particulate removal efficiency: 99.9%

H. Scrubbing liquor: 25% AS solution

I. Gas flow rate from dryer

   1. Caprolactam: 1005 m^3/min (35,500 cfm)

   2. Synthetic: 168 m^3/min (5,920 cfm)

   3. Coke oven: 199 m^3/min (4,200 cfm)

TABLE 6-5. ANNUALIZED COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM
(Caprolactam By-Product Plant with 22.7 Mg/hr Capacity)

Cost Element	Cost (10^3 dollars)
A. Direct Operating Costs	
1. Utilities	
a. Water ($0.40/1000 gal)	17.9
b. Electricity ($0.05/kwh)	54.5
2. Operating Labor	
a. Direct ($10.89/hr @ 4 hrs/shift)	45.7
b. Supervision (15% Direct Labor)	6.9
3. Maintenance	
a. Labor (110% x Direct Labor @ 1 hr/shift)	12.6
b. Materials (100% x Maint. Labor)	12.6
B. Capital Charges	
1. Overhead [80% x (2a + 2b + 3a)]	52.2
2. Fixed Costs	
a. Capital Recovery (16.3% x Capital Costs)	41.6
b. Insurance, taxes, admin. (4% x Capital Costs)	10.2
C. Subtotal	254.2
D. Credit for Recovered Product[a]	(1,012.8)[b]
E. Net Annualized Cost	(758.6)

a Based on a $60/Mg price for by-product AS, with 20% reprocessing charge.
b Values in parenthesis are cost savings.

Source: "Estimating Air Pollution Control Costs," Part II, Table III.

TABLE 6-6. ANNUALIZED COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM
(Synthetic Plant with 13.6 Mg/hr Capacity)

Cost Element	Cost (10^3 dollars)
A. Direct Operating Costs	
1. Utilities	
a. Water ($0.40/1000 gal)	1.9
b. Electricity ($0.05/kwh)	5.8
2. Operating Labor	
a. Direct ($10.89/hr @ 4 hrs/shift)	29.4
b. Supervision (15% Direct Labor)	4.4
3. Maintenance	
a. Labor (110% x Direct Labor @ 1 hr/shift)	8.1
b. Materials (100% x Maint. Labor)	8.1
B. Capital Charges	
1. Overhead [80% x (2a + 2b + 3a)]	33.5
2. Fixed Costs	
a. Capital Recovery (16.3% x Capital Costs)	16.8
b. Insurance, taxes, admin. (4% x Capital Costs)	4.1
C. Subtotal	112.1
D. Credit for Recovered Product[a]	(152.0)[b]
E. Net Annualized Cost	(39.9)

a Based on a $100/Mg price for synthetic AS, with 20% reprocessing charge.
b Values in parenthesis are cost savings.

Source: "Estimating Air Pollution Control Costs," Part II, Table III.

TABLE 6-7. ANNUALIZED COST SUMMARY FOR A VENTURI SCRUBBING SYSTEM
(Coke Oven By-Product Plant with a 2.7 Mg/hr Capacity)

Cost Element	Cost (10^3 dollars)
A. Direct Operating Costs	
1. Utilities	
a. Water ($0.40/1000 gal)	1.9
b. Electricity ($0.05/kwh)	5.8
2. Operating Labor	
a. Direct ($10.89/hr @ 4 hrs/shift)	40.3
b. Supervision (15% Direct Labor)	6.0
3. Maintenance	
a. Labor (110% x Direct Labor @ 1 hr/shift)	11.1
b. Materials (100% x Maint. Labor)	11.1
B. Capital Charges	
1. Overhead [80% x (2a + 2b + 3a)]	45.9
2. Fixed Costs	
a. Capital Recovery (16.3% x Capital Costs)	14.9
b. Insurance, taxes, admin. (4% x Capital Costs)	3.7
C. Subtotal	140.7
D. Credit for Recovered Product[a]	(9.6)[b]
E. Net Annualized Cost	131.1

[a] Based on a $60/Mg price for by-product AS, with a 20% reprocessing charge.
[b] Values in parenthesis are cost savings.

Source: "Estimating Air Pollution Control Costs," Part II, Table III.

offset annualized costs, which improves the cost effectiveness for particulate removal. In this study, the recovery credits in a 22.7 Mg/hr caprolactam by-product AS plant and in a 13.6 Mg/hr synthetic AS plant create a net savings in annualized costs. This does not hold true for the coke oven by-product AS plant because a much lower AS production rate (2.7 Mg/hr) and lower uncontrolled emissions limit the collected particulates available for capture and process recycle.

Credits for recovered product will vary directly with changes in the market price of ammonium sulfate. Credits for this cost study are calculated based on a March 1984 average wholesale price of $60/Mg for by-product AS and $100/Mg for synthetic granular AS, with a 20 percent reprocessing charge.[1] Average U.S. market prices for AS over the past years are presented in Table 6-8.

6.3 Cost Effectiveness

The cost effectiveness of controlling AS particulate emissions can be related to the quantity of pollutants removed from dryer exhaust streams by using the annualized costs as a basis. This study utilizes a 99.9 percent efficient particulate recovery rate by the control device, and particulate emission rates from typical AS dryers as listed in Chapter 2. The calculated cost effectiveness of venturi scrubbers for AS particulate control at each model plant is presented in Table 6-9. The cost effectiveness varies from a savings of $36/Mg of particulate removed in the caprolactam by-product plant to a cost of $655/Mg of particulate removed in the coke oven by-product AS plant. The synthetic AS plant in this study demonstrated a savings of

TABLE 6-8. AVERAGE U.S. RETAIL PRICE FOR AMMONIUM SULFATE

Month/Year	Price ($/ton)
March 1984	150
March 1983	146
March 1982	165
March 1981	150
March 1980	138
March 1979	118
March 1978	109
March 1977	101
April 1976	98.20
April 1975	148
April 1970	52.40
April 1965	53.40

Sources:

Fertilizer Trends 1982 - TVA National Fertilizer Development Center.
Prices Paid by Farmers - Crop Reporting Board, SRS, USDA, October 1983.
Information provided from Paul Andalinas, USDA.

TABLE 6-9. COST EFFECTIVENESS OF AS PARTICULATE RECOVERY USING VENTURI SCRUBBERS (March 1984 dollars)

Plant Type	Plant Size Mg/hr (ton/hr)	Annualized Cost ($1000/yr)	AS Removed[a] (Mg/yr)[a]	Cost Effectiveness ($/Mg AS Removed)
Caprolactam	22.7 (25)	[758.6][b]	21,095	[36]
Synthetic	13.6 (15)	[39.9]	1,915	[21]
Coke Oven	2.7 (3)	131.1	200	655

[a] Based on 99.9% collection efficiency.

[b] Brackets indicate cost savings.

$21 per Mg particulate removed. These values are sensitive to AS market prices and particulate recovery efficiencies.

6.4 References

1. Information obtained in a telephone conversation between E. Harre, TVA National Fertilizer Development Center, and Peter Schindler, U.S. EPA, on September 7, 1984.